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Original communication

Post-burning fragmentation of calcined bone: Implications for remains recovery from fatal fire scenes

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ABSTRACT

This research assesses how short term delays in time-until-recovery can affect the quality and quantity of burnt bone recovered from a fatal fire scene. Knowledge of trends in post-burning remains fragmentation will enable investigators to prioritise remains recovery and implement recovery protocols appropriately. By comparing calcined bone fragments recovered 0, 24, 56 and 168 h (1 week) after experimental burns, this research describes remains fragmentation over time. *Sus scrofa* (domestic pig) limbs were burnt in a series of wood fuelled fires with calcined remains recovered at the specified time intervals. Bone fragments were sorted into 12 size based categories and the proportional weight of each category compared to observe differences in fragmentation over time. Results reveal marked increases in fragmentation when recovery is delayed by 24 h but less change in fragmentation between 24 and 56 h delay when breakage is reduced in the larger fragments. Between 56 and 168 h delay large increases in fragmentation occurred across all fragment sizes. These results indicate that short term recovery delays (24 h) can be detrimental to remains condition, but if remains recovery cannot be completed soon after the fire intermediate delays (56 h) are less significant. Longer term delays (168 h) are again potentially highly detrimental.

1. Introduction

The recovery of calcined bone from a fatal fire scene is a painstaking and complex process. Not only is calcined bone fragile and typically highly fragmented, making identification and collection of remains challenging, but recovery needs to occur within the bounds of the larger investigation.[1,2] Any fatal fire scene needs to be determined safe before investigators can enter and the needs of the police, fire investigator, medical examiner or coroner, and other professionals require coordination to ensure all investigators can complete their work in a timely manner with maximum information acquisition for all.[1,3] To ensure remains recovery is appropriately prioritised and implemented within the needs of other investigators, knowledge of the trends in remains degradation over time is vital. These patterns of remains fragmentation are currently not well recognized and improving our understanding in this area will allow recovery protocols to be adjusted, improving the quantity and quality of material recovered. The ability to predict fragment sizes will enable investigators to determine the best approach for trained searchers, enhancing their ability to detect bone material. It will ensure that optimal equipment and search strategies are used from the beginning of the search and recovery process, minimising recovery-associated damage to the remains.

When human remains are burnt and the soft tissue is destroyed, underlying bone is exposed to the burn environment. As bone burning progresses, the bone material is transformed from its natural state to calcined bone through a number of intermediary stages which result in observable heat-induced changes in gross and microscopic appearance, colour, size and shape.[4–6] During burning, as bone loses water and organic components and the hydroxyapatite crystals increase in size, overall size and shape changes affect the structural integrity of the bone material by altering the stress–stain relationships within each bone element, leading to mechanical failures and fracturing.[7,8] The loss of organic material reduces bone elasticity, further promoting fragmentation of fully calcined material.[7–9] Anthropological analysis is possible on these fragmentary remains, and to capitalize on the information which can be obtained, recovery needs to be maximized for both quantity and quality of material recovered.

2. Methods and materials

To investigate the effect of delayed recovery on bone fragmentation fleshed *Sus scrofa* (domestic pig) limbs were burnt in a series

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of three outdoor wood fires, as outlined in Table 1. Three delay periods (24, 56 and 168 h) were investigated, and compared with fragmentation following recovery the day after the fire (the baseline marked as 0 h delay). The delay periods were selected to represent a range of time more commonly encountered during fatal fire scene investigations as determined from an extensive review of local Alberta case files. Wood burning fires were used to ensure a repeatable burn environment that experienced changes in temperature and physical environment throughout the burn event. *S. scrofa* limbs were sourced from local butchers, and as such their exact age at death was unknown but their similar size and patterns of unfused epiphyses suggest they were of all of a similar age, between eight and 10 months.[10]

For each burn event limbs were placed in two fires, one with material for immediate recovery, and a second with material for recovery following the three delay periods. In the second fire, limbs for each of the delay periods of 24, 56 and 168 h, were separated by 1.25 cm diameter, 0.5 m iron rods (rebar). In the first burn event limbs were placed directly on the ground and in latter burn events limbs were placed on a wood base to promote burning and calcination of inferior surfaces. Wood and newspaper were used to build stable, burnable structures that were lit and left undisturbed except for periodical additions of wood fuel. No solvents were used to ignite, or sustain the fires. Wood fuel was added by hand, avoiding any direct contact with the bone. Fires were sustained for four to five hours until full calcination was observed, at which point they were left to burn out and cool overnight. The wood fuel consisted of a spruce/pine mix of 2″ × 4″ and 2″ × 6″ lumber, commonly found in the Alberta region and often used in home construction.[11] Similar time and temperature profiles for each fire segment was confirmed by temperature data collected from type J thermocouples placed amongst each limb group (0, 24, 56, and 168 h delay) with temperatures recorded at one minute intervals using a DaqPRO 5300 data logger (See Table 1).

Following burning, bone remains were recovered from the burn site at the specified delay periods. Recovery at 0 h delay occurred in the mid-morning of the day after burning, allowing for full cooling and temperature stabilization. Prior to collection the area was assessed for any evidence of animal disturbance. Bone remains were collected by the author by hand, using tweezers for smaller fragments with care taken to ensure no additional damage to any bone fragments. Bone fragments were stored in partially air filled polyethylene, sealable bags and supported in the short term by toilet tissue for immediate transport to the laboratory where they were removed from the bags without delay, evaluated for any possible transportation damage, and stored on soft-surfaced paper trays. In the laboratory the bone material was sorted into one of 12 defined categories within three series based on size and shape (See Fig. 1). The *Small series* consists of three categories, numbered 1 through 3, where the shortest fragment dimension is less than 5 mm. The second series, the *Longitudinal series*, consists of 4 categories, Categories 4 through 7 and in this series the longest dimension is greater than twice the second longest dimension. In the third series, the *Non-longitudinal series*, the longest dimension must be less than twice the second longest dimension and there are 5 categories within this series, Categories 8 through 12. The size categories were developed from a number of preliminary test/practice burn events where material was sorted into perceived naturally occurring clusters. Fragments with two dimensions less than 5 mm and one dimension less than 10 mm were excluded from analysis as although potentially informative, these could not be collected consistently and thus true comparisons were not possible.

Sieves were not used to separate material as they can cause considerable mechanical damage to fragile materials and do not separate shape differences. By measuring three dimensions fragments could be separated into three distinct shape series (Small, Longitudinal and Non-longitudinal) and fragmentation characteristics could be assessed within each series. The number of categories used was based on preliminary test/practice burns to ensure that size categorisations reflected the material at hand and did not arbitrarily divide clear size groupings and thus obscure any trends in the data. The size categories selected reflect clear clusters observed in the preliminary test/practice burns. Following sorting each category was weighed and the proportional mass determined. Proportional mass was calculated as percentage weight for each category within each limb group (0, 24, 56 and 168 h delay). Proportional masses were calculated to allow direct comparisons between each category in the differing delay periods.

3. Results

3.1. 0 h and 24 h delay

When the recovery of remains is delayed by 24 h the effect on fragmentation is mixed, as seen in Fig. 2. In the Small series there is a clear trend of higher fragmentation when recovery is delayed with higher proportional masses seen in all categories for almost all burn events. In Category 2, burn 3, lower proportional masses were recorded following 24 h delay, but both other burn events showed large increases in proportional mass. This increase in proportional mass is interpreted as being the major trend with the isolated data point showing a reduction in fragmentation originating from variable factors in the burn or post burn environment altering proportional mass in this specific burn event and category.

In the Longitudinal series the effect of delayed recovery is more complex. In Category 4 there is no indication of a difference in fragmentation between 0 and 24 h delayed recovery. In Category 5 responses vary between the burns, but both burns 1 and 3 show clear reductions in proportional mass when recovery is delayed. In

Table 1
The number of *Sus scrofa* limbs used in the burn events and burn characteristics for each limb group.

Burn event	Fire 1			Fire 2								
	0 h delay			24 h delay			56 h delay			168 h delay		
	# of limbs	T_{max} (°C)	Time at T_{max} (min)	# of limbs	T_{max} (°C)	Time at T_{max} (min)	# of limbs	T_{max} (°C)	Time at T_{max} (min)	# of limbs	T_{max} (°C)	Time at T_{max} (min)
1	2	741	100	2	790	100	1	843	60	2	876	80
2	3	701	70	2	562	70	2	–	–	2	602	100
3	1	848	80	1	869	90	1	843	70	1	820	110

All limbs used were forelimbs except for burn 3 which used hindlimbs.
T_{max} refers to the highest temperature reached in any one 10 min interval, averaged from 1 min data.
Time at T_{max} refers to the time since fire start and marks the beginning of the 10 min interval.
No temperature data was recorded for Burn 2, 56 h delay due to thermocouple probe failure.

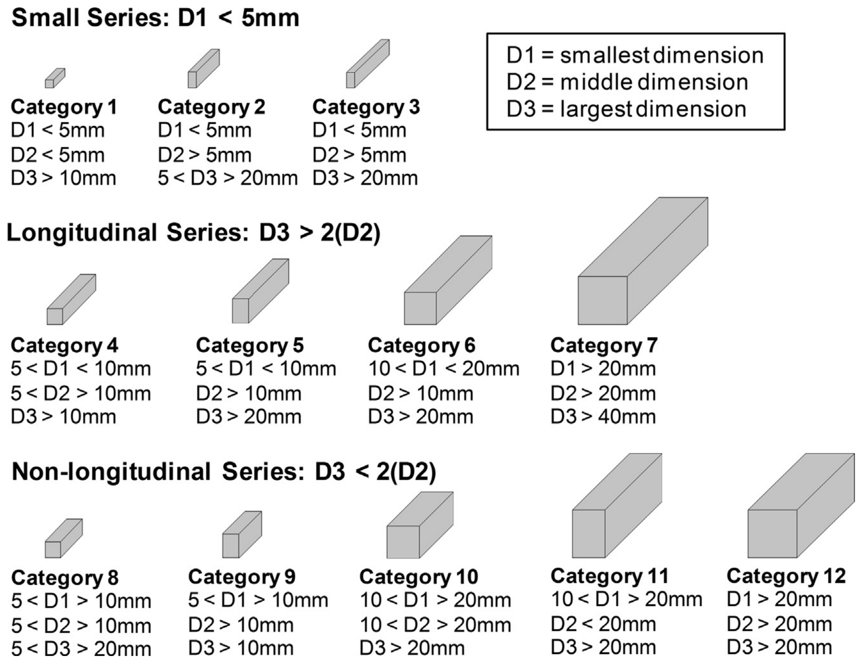

Fig. 1. Size categories used for sorting calcined bone. In the *Small series* the shortest fragment dimension is always less than 5 mm. This series includes categories 1–3. In the *Longitudinal series* the longest dimension is greater than twice the second longest dimension. This series includes categories 4–7. In the *Non-longitudinal series* the longest dimension must be less than twice the second longest dimension. This series includes categories 8–12.

Category 6 two burns (1 and 2) again show reductions in proportional mass following a delayed recovery, although this is not seen in burn 3 where proportional mass was slightly higher after the delay. In Category 7 there is one outlier in burn 1 where proportional mass increases with delayed recovery, but in burns 2 and 3 proportional mass is markedly lower when recovery is delayed by 24 h. This general trend of lower levels of proportional mass following recovery indicates increased fragmentation when recovery is delayed by 24 h compared to immediate recovery.

In the Non-longitudinal series the pattern of difference between 0 and 24 h delay varies. In Category 8 there appears to be no difference between 0 and 24 h delay with proportional masses showing very similar levels. In Category 9 proportional masses are lower at 24 h delay in burns 1 and 3, but not burn 2. The opposite pattern is seen in Category 10 where proportional masses are higher following delay for burns 1 and 3. The pattern is again reversed in Category 11 where, like Category 9, proportional masses are lower following delay in burns 1 and 3 but higher in burn 2. This series of increases and decreases in proportional masses likely occurs when higher fragmentation in a larger category increases levels in the category below and lower fragmentation in a larger category decreases levels in the category below. In Category 12 proportional mass is lower following delayed recovery in burn 1 and 2 but not in burn 3 where it is markedly higher. This burn 3 data point is likely not representative of general trends in Category 12, especially as this category often consists of a few large fragments where one or two fracturing events can have a marked effect on proportional mass. In general, for the Non-longitudinal series, fragmentation is increased when recovery is delayed by 24 h.

3.2. 24 h and 56 h delay

To assess fragmentation following a 56 h delay until recovery proportional masses for each size category were compared to those observed after a 24 h delay as seen in Fig. 3. In the Small series proportional masses are generally higher following the longer delay period. As observed when comparing 0 and 24 h delay there is no marked change in proportional mass in Category 1 at 56 h delay. In Categories 2 and 3 all but one burn event show higher proportional masses after 56 h delay and for the one data point that does not show an increase the decrease is very minor. This pattern suggests higher levels of fragmentation following the longer delay period with material from the Longitudinal and Non-Longitudinal series breaking down and increasing bone volume in the Small series.

In the Longitudinal series the patterns of fragmentation change vary between categories. As observed when comparing 0 and 24 h delay, there is little change in proportional mass in Category 4 when the delay period is extended. In Category 5 increasing the delay period to 56 h results in higher proportional masses in all burns. This increase is not observed in Category 6 where burn 1 shows much higher levels after the longer delay, burn 2 shows similar levels and burn 3 shows much lower levels. These values are matched in Category 7 by the opposite pattern in burns 1 and 3 with the longer delay resulting in lower levels in burn 1 and higher levels in burn 3. These paired values likely arise because Category 7 often consists of only a few bone pieces and one or two fragmentation events can have a marked effect on category bone mass. Burn 2 levels in Category 7 show higher proportional masses after a 56 h delay. Considering the changes in proportional mass across all categories in the Longitudinal series there is a general trend of increased fragmentation with a longer delay period although this increase is characterised by a reduction in total bone volume recovered and not a marked loss of Category 5, 6 or 7 material.

In the Non-longitudinal series fragmentation patterns again vary between the categories. As seen previously there is almost no difference between the delay periods in Categories 8 and 9. In Category 10 proportional mass is slightly lower after 56 h delay in burns 1 and 2 but higher in burn 3. In Category 11 proportional mass is higher at 56 h delay in burns 1 and 3 but lower in burn 2 and in Category 12 proportional mass is higher in burn 1, similar in burn 2 and lower in burn 3 following the longer delay period. These

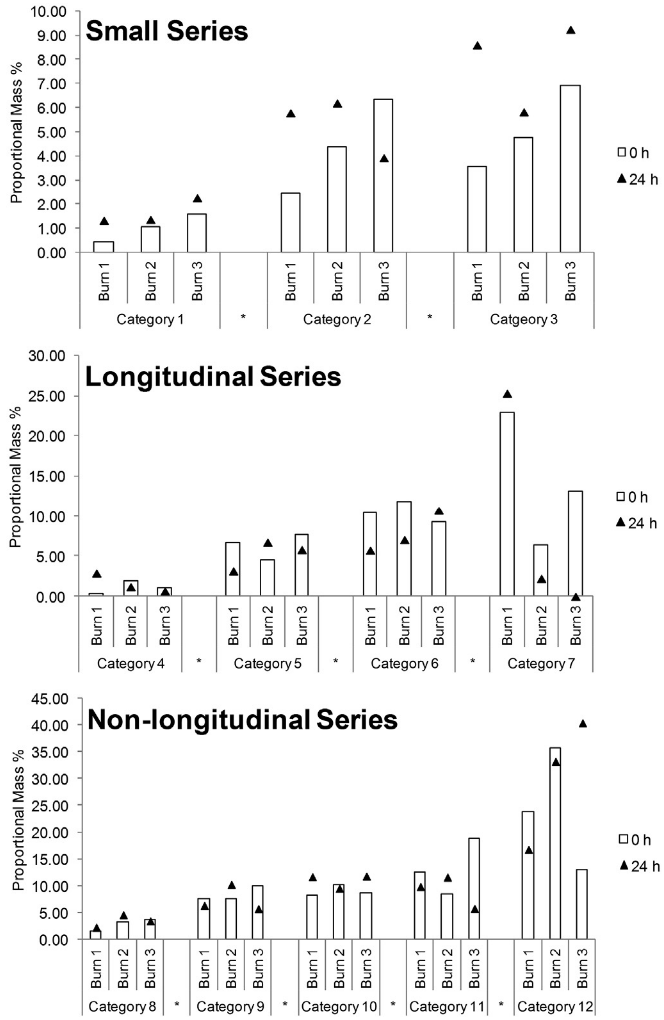

Fig. 2. Proportional mass distributions at 0 and 24 h delay until recovery.

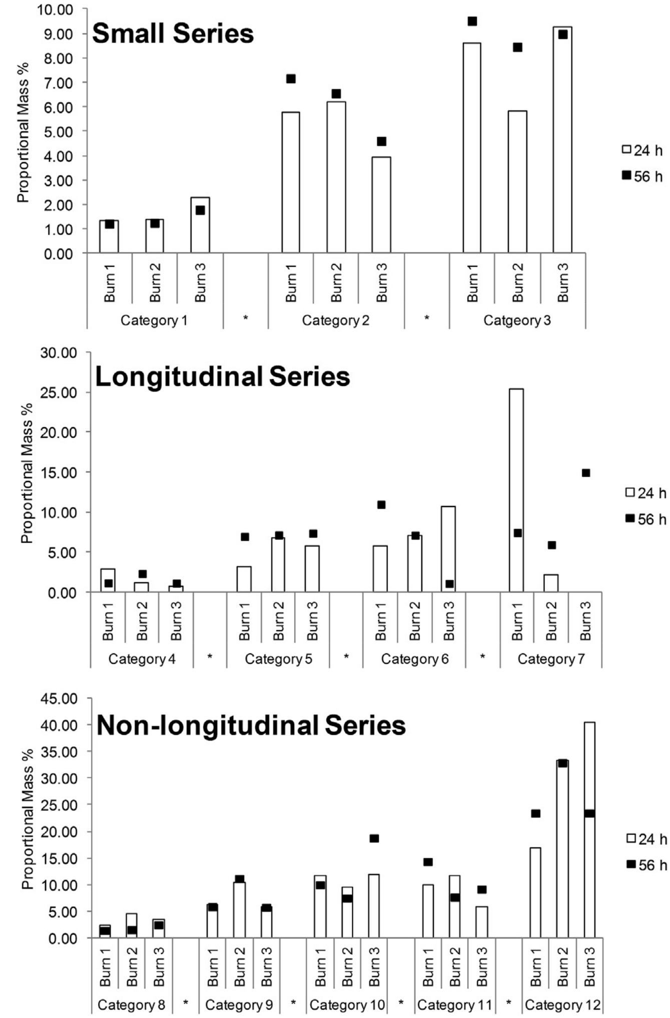

Fig. 3. Proportional mass distributions at 24 and 56 h delay until recovery.

data indicate that, as in the Longitudinal series, larger fragments are remaining relatively stable with some loss of material and fragmentation of smaller bone pieces.

3.3. 56 h and 168 h delay

Fragmentation following a delay of 168 h before recovery is compared to that following a delay of 56 h before recovery as seen in Fig. 4. In the Small series results indicate a general drop in proportional mass when recovery is delayed 168 h rather than 56 h. In Category 1 there is little difference in proportional mass between the delay periods, likely because the small nature of the material requires large changes in bone volume before marked changes in mass are observed. In Categories 2 and 3 the proportional mass after 168 h delay is similar to or lower than that observed at 56 h delay.

In the Longitudinal series Category 4 shows almost no difference in proportional mass between the delay periods, a pattern seen in all delay period comparisons. In Category 5 proportional masses are consistently lower at 168 h delay than at 56 h delay and in Category 6 results are higher at 168 h except in burn 1 where they are lower. In Category 7 results vary between burns with burns 1 and 3 showing higher proportional masses after 168 h delay and burn 2 showing lower levels. The increased proportional masses in the largest categories suggest that bone fragments in these categories are not fragmenting significantly.

In the Non-longitudinal series Category 8, like Category 4 in the Longitudinal series, shows no difference in proportional mass between the different delay periods. In both Categories 9 and 10 two burn events show very little difference between delay periods with the remaining burn event showing higher levels in Category 9 and lower levels in Category 10 after a longer delay period. Category 11 shows a similar pattern to Category 9 with two burn events showing similar proportional masses between delay periods and the third burn event showing an increase in proportional mass after 168 h delay. In Category 12 burns 1 and 2 show higher proportional masses and burn 3 shows lower levels. Overall there is a consistent pattern for little difference between the delay periods with slight increases in proportional mass in Category 12. This pattern is especially evident in burns 1 and 2. In burn 3 there appears to have been more fragmentation of Category 12 material at 168 h which increases levels in Category 11, however this change in patterning can result from only one or two fracture events as there are typically few fragments in Category 12. The marginal change in proportional masses after an increased delay period suggests increased fragmentation across all categories.

4. Discussion

When the recovery of calcined remains is delayed by 24, 56 or 168 h there is a clear trend of increasing fragmentation over time.

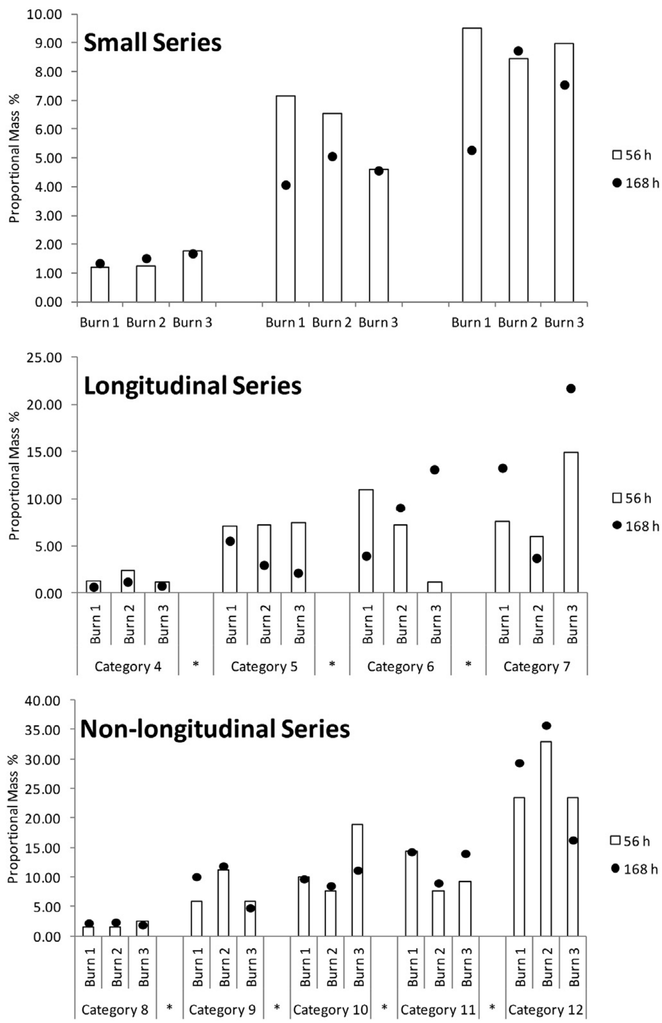

Fig. 4. Proportional mass distributions at 56 and 168 h delay until recovery.

This trend is expected as continued exposure to a variable environment, with changes in temperature, humidity and other factors, introduce new and changing stresses and strains to the calcined bone. The brittle and fragile bone material is unable to withstand these changes and progressively fragments, either by the flaking off of small pieces or by fracturing into a number of pieces. The patterns of fragmentation and the bone pieces most affected by the delays in recovery depend on the time delay experienced (Table 2).

When remains recovery is delayed by 24 h fragmentation increases. This increase in fragmentation affects all categories and is evenly distributed between the three series. The fragmentation patterns suggest that almost all bone pieces are breaking down in a similar manner with no increased survival or degradation of any one fragment size or shape. The proportional mass data does suggest that time until recovery does not affect the smallest categories in each series but this is likely an artefact of the small nature of the bone pieces within these categories and should not be taken to indicate similar levels of fragmentation at 0 and 24 h delayed recovery. As the bone pieces are so small in these categories large changes in bone volume are required before marked changes in proportional mass will be observed. Increased fragmentation of these bone pieces may result in them becoming too small for collection, thus removing them from analysis and lowering category bone mass.

The overall increase in fragmentation is expected as after a delay of 24 h, remains were exposed to an additional temperature cycle as well as fluctuations in other environmental conditions. During the first 24 h post burning the fires burnt out and the retained heat and cooling process would have altered the bone environment such that remains recovered at this time (0 h delay) would not have been exposed to a typical environmental cycle. Remains recovered after a delay of 24 h would have been exposed to these changes in ambient temperature, humidity and other factors which likely impact fragmentation. In burns 1 and 3 temperatures dropped below freezing and any water associated with the remains would have frozen and expanded, introducing new stresses onto (and into) the brittle material. In burn 2 rainfall increased the moisture content of the fire scene and recovered bone which likely affected fragmentation. This effect of ‘first exposure’ after a delay of 24 h can explain the widespread fragmentation across the range of bone sizes as all bone fragments experienced conditions and stress–strain relationships for the first time.

At 56 h delay until recovery, remains fragmentation again increases, but unlike at 24 h delay this increase is not widespread. In the Small series proportional masses were consistently increased indicating increased bone volume, likely from fragments breaking off larger bone pieces. Proportional masses in the Longitudinal series categories also generally increased when recovery was delayed by 56 h compared to 24 h suggesting bone fragments remained relatively stable and the total recovered bone mass was reduced. This total bone mass reduction may have resulted from bone pieces, too small to be recovered, breaking off the larger, relatively stable fragments as well as fragmentation of Category 4 bone pieces. In the Non-longitudinal series a similar pattern is observed with larger bone pieces remaining relatively stable and

Table 2
Summary of post-burning fragmentation after 24, 56 and 168 h delay in recovery.

	24 h delay	56 h delay	168 h delay
Small series	Increased proportional masses compared to 0 h delay indicating increased fragmentation.	Increased proportional masses compared to 24 h delay indicating increased fragmentation.	Reduced proportional mass due to loss of recoverable material indicating increased fragmentation.
Longitudinal Series	General trend of decreased proportional masses compared to 0 h delay indicating increased fragmentation.	Increased proportional masses in larger categories indicating greater stability of larger fragments but increased fragmentation of smaller fragments.	Increased proportional masses in only the largest categories indicating increased fragmentation in all smaller categories.
Non-longitudinal Series	Fluctuating proportional masses between adjacent categories suggests increased fragmentation in larger categories increasing proportional mass in the adjacent lower category.	Increased proportional masses in larger categories indicating greater stability of larger fragments but increased fragmentation of smaller fragments.	Little difference in proportional mass compared to 56 h delay with some increases in Category 12 indicating increased fragmentation in all categories but the largest.
Overall	Increased fragmentation across all series.	Increased fragmentation in smaller categories with larger fragments remaining more stable.	Increased fragmentation in all but the largest categories where fragments remain more stable.

small fragments flaking off these pieces combined with fragmentation of Category 8 and 9 bone pieces reducing the total volume of bone recovered.

The stability of larger bone pieces after a delay of 56 h is likely linked to overall structural design and integrity although further work is required to fully understand this phenomenon. Larger fragments typically consist of almost complete bones or bone portions and maintain some of their pre-burning shape where as smaller bone pieces generally consist of unidentifiable fragments which have broken off elements and are not structurally complete. These differences in completeness may result in smaller bone pieces being unable to withstand changes in stress–strain relationships introduced between 24 and 56 h delay. This size based effect is observed when comparing 24 and 56 h delay as by 56 h delay bone pieces have already responded to the exposure to various environmental conditions and any 'weak spots' in larger fragments have been tested. Between 24 h and 56 h delay there is less exposure to new environmental conditions and the larger bone pieces that resisted fragmentation at 24 h delay continue to do so. Fragmentation of smaller bone pieces still occurs, however, as these structurally weaker fragments are less able to withstand continued exposure and the associated changes in stress–strain relationships. These smaller fragments are also less able to withstand the cumulative effects of increased time of exposure to such factors as increased rainfall or increased hours of sunshine.

When remains recovery is delayed by 168 h the trend of stability of larger fragments observed after 56 h delay is still observed. In the Small series the drop in proportional mass indicates a reduction in recoverable material, with higher levels of fragmentation of smaller bone pieces resulting in less material being recovered from the scene. The reduction in recoverable material also impacts proportional masses in the Longitudinal series where proportional mass increases in Categories 6 and 7 suggest these larger fragments are not fragmenting substantially between 56 h and 168 h delay. This pattern is similar to that seen at 56 h delay however by 168 h delay bone in Category 5 is breaking down and not remaining stable as it did at 56 h delay. The patterns of proportional mass change in the Longitudinal series suggest that when recovery is delayed by 168 h fragmentation in this series occurs across almost all categories at a rate equalling the reduction in recoverable material. Larger, Category 12, fragments seem able to withstand this fragmentation somewhat and remain relatively stable. Overall, the change in fragmentation seen between 56 and 168 h delay supports the idea of better structural integrity and bone completeness providing better resistance to fragmentation. Bone fragments in the largest categories are typically the most complete and continue to withstand the cyclical and cumulative changes in environmental conditions between 56 and 168 h delay.

5. Conclusion

Calcined bone is a brittle and fragile material prone to progressive fragmentation which can make recovery and analysis very challenging. Knowledge of the time frame of this fragmentation is key to aiding the recovery process as it allows appropriate decisions to be made regarding the critical nature of scene processing. It is clear that immediate recovery is advantageous as even a delay of 24 h results in breakdown of the material across all bone pieces. If recovery cannot be completed within 24 h it is perhaps less critical that remains be recovered immediately as between 24 and 56 h continued fragmentation is somewhat restricted to smaller bone fragments. Smaller bone fragments, while still potentially highly diagnostic and valuable, usually exhibit fewer identifying features and are less likely to be fundamental to the laboratory investigation. By 168 h delay the larger bone pieces have also begun to fragment and any delay in recovery may result in significant further losses in valuable material for analysis. Knowledge of these patterns of fragmentation will allow investigators to prioritise the needs of multiple investigators at a fire scene and adapt recovery techniques to the remains in hand, thus ensuring optimal collection of material critical for identification, and the greatest care in the recovery of remains for return to family.

Ethical approval

The author confirms that this project has fulfilled the ethics approval requirements of the University of Alberta.

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Conflict of interest

The author confirms that there are no known conflicts of interest associated with this publication.

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